2.25 Signal Integration Conceptual Model Specification

In many radar systems, returns from multiple pulses are used to make a detection decision. Signal integration is the summation of several successive signal and noise pulses for the purpose of improving the detectability of target signals. Integration gain is the resulting improvement factor in the signal-to-noise ratio.

Integration may be accomplished in the radar receiver either before or after the second (amplifier) detector. Integration before the second detector is called pre-detection or coherent integration, while integration after the second detector is called post-detection or noncoherent integration. Some pre-detection integration methods are addressed in other FEs (clutter rejection in Sections 2.23 and 2.24, and pulse compression in Section 2.26). The signal integration FE described in this section includes only post-detection processing.

Many different techniques can be used to provide noncoherent integration. In simple systems, data are presented directly for display on a cathode ray tube and are visually integrated by the operator. In visual processing, the luminous persistence of the return plus the memory of the operator allow several pulse returns to be added. This physical-biological process is very complex and difficult to model. Rather than being modeled directly, it is usually approximated by using algorithms that describe hardware integrators.

In radars with hardware integrators, electronic memory and integration circuits are provided after the detection-envelope circuits. The ability of these noncoherent integrators to provide improved detectability is primarily dependent on reducing sensitivity to the stochastic nature of noise rather than on the signal characteristics. However, the integration gain depends on the target fluctuation type (Section 2.4) as well as on the radar detection-envelope type, integrator type, and settings related to probability of detection and probability of false alarm.

The intent of the Signal Integration FE in ALARM 3.0 is to simulate the noncoherent integration performed in target detection for radar systems with some common types of detectors and integrators.

2.25.1 Functional Element Design Requirements

This section contains the design requirements for implementing the Signal Integration Functional Element in ALARM 3.0.

1. ALARM will simulate the gain due to noncoherent, post-detection signal integration in radar systems with common types of detectors and integrators.

This implementation may also be used to approximate operator visual processing.

2. The simulation of integration gain in ALARM will include the effects of fluctuating targets.

2.25.2 Functional Element Design Approach

This section describes the design approach (equations and algorithms) implementing the design requirements of the previous section. The ALARM 3.0 implementation is based primarily on an earlier subroutine called THRESH, developed in 1985 by Jon Covala for Swerling, Manasse, and Smith [A.1-26] that was based on the methodology given in Blake [A.1-25].

Design Element 25-1: Integration Gain

The integration gain, G, is the improvement in detectability due to integrating N pulses (equation 7.52 of [A.1-25]). The detectability factor, D_o, is defined to be the minimum value of S/N which produces detection. Thus, integration gain can be written as

$$G = D_0(1) - D_0(N) \qquad (2.25\text{-}1)$$

where	G	=	integration gain for N pulses integrated (dB)
	$D_o(1)$	=	detectability factor for single pulse (dB)
	$D_o(N)$	=	detectability factor for N pulses integrated (dB)

The calculation of D_o depends on $\overline{D}_o$, the detectability factor for a non-fluctuating target. $\overline{D}_o$ is described in the following section.

Design Element 25-2: Detectability Factor with No Fluctuations

In equations 2.29-2.33 of [A.1-25], the detectability factor $\overline{D}_o(N)$, for a nonfluctuating target, is defined as follows:

$$\overline{D}_0(N) = \frac{X_0}{4H_N}\left[1 + \sqrt{1 + \frac{16H_N}{\zeta X_0}}\right] \qquad (2.25\text{-}2)$$

where X_o is computed by

$$X_0 = (g_{fa} + g_d)^2 \tag{2.25-3}$$

with

$$g_{fa} = 2.36\sqrt{(-\log P_{fa})} - 1.02 \tag{2.25-4}$$

and

$$g_d = \frac{1.231t}{\sqrt{1-t^2}} \tag{2.25-5}$$

where	P_{fa}	=	probability of false alarm
	t	=	$0.9\ (2P_d - 1)$
	P_d	=	probability of detection
	H_N	=	equivalent number of pulses integrated
	ς	=	asymptotic efficiency of the envelope detector

These equations are implemented in ALARM for both single pulse and multiple pulse cases, so that both $\overline{D}_o(1)$ and $\overline{D}_o(N)$ are calculated. In this calculation, P_d and P_{fa} are user inputs, which must satisfy $0.1 \le P_d \le 0.9$ and $10^{-12} \le P_{fa} \le 10^{-4}$ [A.1-25]. The asymptotic efficiency, ζ, is defined (table 2.1, [A.1-25]) by

$$\zeta = \begin{cases} 1.000 & \text{for square-law detector} \\ 0.915 & \text{for linear detector} \end{cases} \tag{2.25-6}$$

The equivalent number of pulses integrated depends on the actual number of pulses integrated, the integrator type, and the signal variation [A.1-25]. In ALARM 3.0, H_N is simply set to the user-input NPULSE, defined as the number of pulses integrated; i.e.,

$$\begin{aligned} H_1 &= 1 \\ H_N &= N \end{aligned} \tag{2.25-7}$$

This is valid for an ideal or uniform-weight integrator with no signal variation. For other types of integrators or cases with signal variation (due to movement of the radar beam with respect to the target), the user must precalculate H_N and input that value as NPULSE.

Design Element 25-3: Inclusion of Fluctuation Loss

Before using equation (2.25-1) to calculate the integration gain, the detectability factors ($\overline{D}_o$s) are adjusted to account for a fluctuating target. The following equation is based on the discussion on page 72 of [A.1-25].

$$D_0(i) = \overline{D}_0(i) + L_f(i) \qquad for \quad i = 1,N \tag{2.25-8}$$

where $D_o(i)$ = detectability factor (including fluctuation) for i pulses (dB)
$\overline{D}_o(i)$ = detectability factor (not including fluctuations) for i pulses (dB)
$L_f(i)$ = fluctuation loss for i pulses (dB)

The calculation of fluctuation loss is described in Section 2.4.

2.25.3 Functional Element Software Design

This section contains the software design necessary to implement the signal integration requirements and design approach. It is organized as follows: the first subsection describes the subroutine hierarchy and gives descriptions of the relevant subroutines; the next subsection contains logical flow charts and describes important operations represented by each block in the charts; the last subsection contains a description of all input and output data for the functional element as a whole and for each subroutine that implements signal integration.

Signal Integration Subroutine Design

The FORTRAN call tree implemented for the Signal Integration Functional Element in the ALARM 3.0 code is shown in figure 2.25-1. The diagram depicts the structure of the entire model for this functional element, from ALARM (the Main program) through the least significant subroutine implementing integration. Subroutines which directly implement the functional element appear as shaded blocks. Subroutines which use functional element results appear with bands at the ends. Each of these subroutines is described briefly in table 2.25-1.

Table 2.25-1 Subroutine Description

MODULE NAME	DESCRIPTION
GETRCS	Extracts and interpolates the RCS of the target
PULDOP	Cycles through flight path or plot matrix points, controls calculation of factors in radar range equation for pulse doppler radar
PULSED	Cycles through flight path or plot matrix points, controls calculation of factors in radar range equation for pulsed radar
RDRERR	Checks for legality of user input data for the radar parameters
RDRINP	Reads the user inputs for radar parameters
RDRINT	Performs initial processing on user inputs for radar parameters
RDRPRT	Prints user inputs for radar parameters
THRESH	Calculates integration gain and fluctuation loss (or the detection threshold of the radar) given probability of detection and false alarm
Note: Modules implementing the signal integration functional element are identified in **bold** letters	

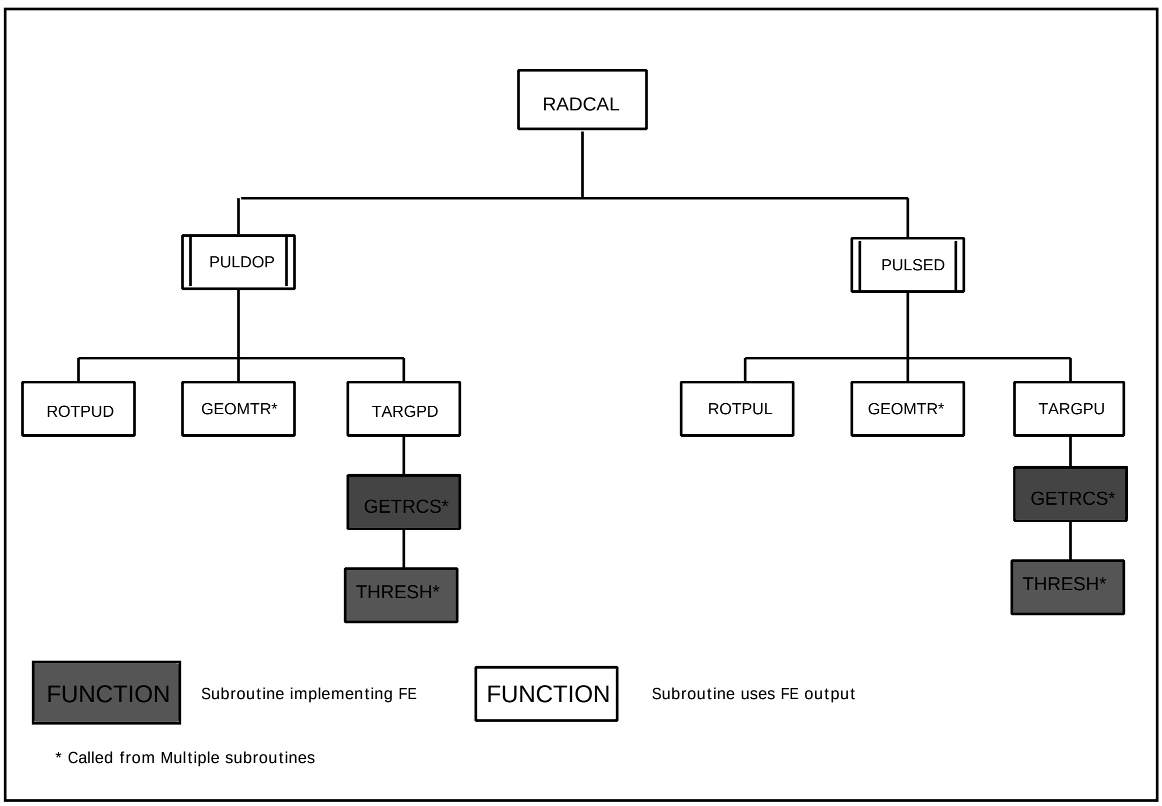

Figure 2.25-1 Call Hierarchy for Signal Integration

Functional Flow Diagram

Figure 2.25-2 shows the top-level logical flow of the signal integration implementation. Subroutine names appear in parentheses at the bottom of each process block. The numbered blocks are described below.

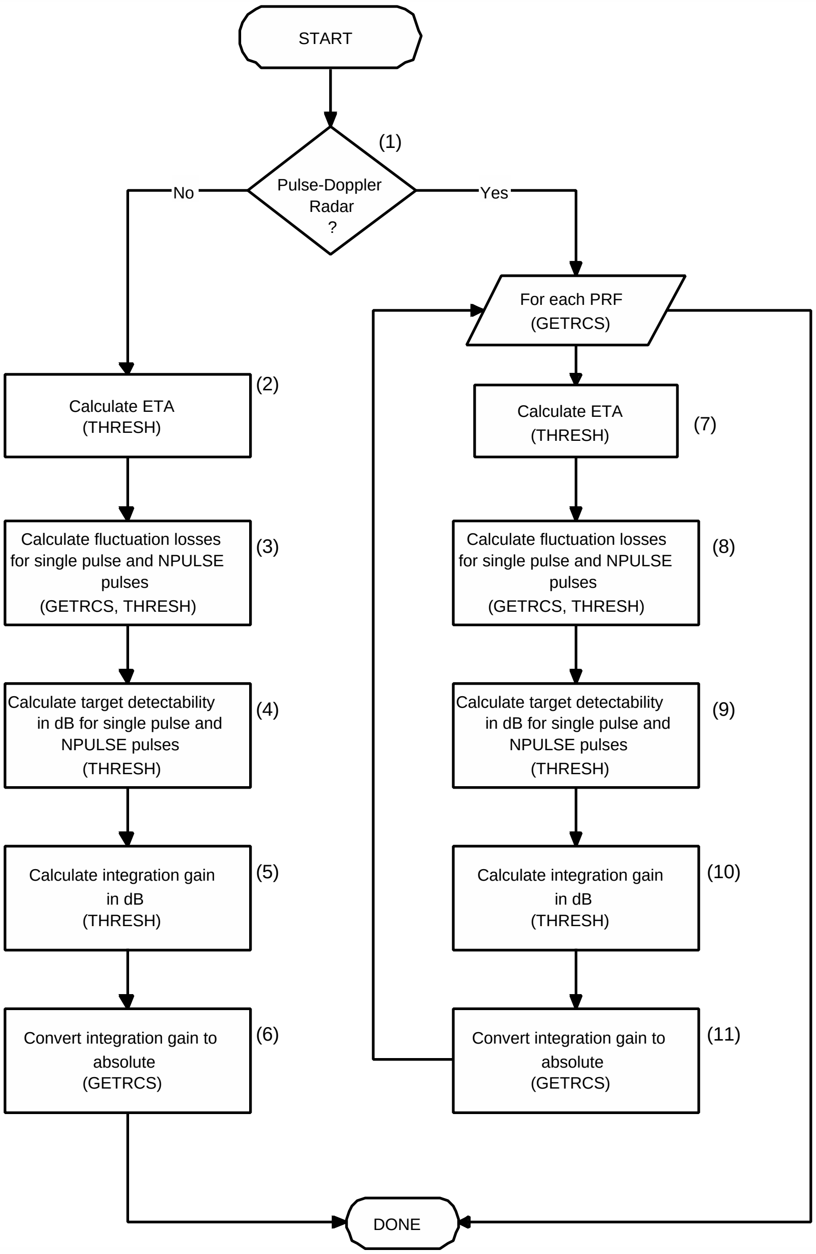

Figure 2.25-2 Signal Fluctuation Logical Flow

Note: This flow chart does not depict the exact flow of the logic in subroutines GETRCS and THRESH because the calculations for the signature fluctuations are inextricably intertwined with those for signal integration. Figure 2.25-2 is an attempt to display the major logical steps of signal integration without showing the details of the other FE (see Section 2.4).

Block 1: If the radar is pulsed, it has a single frequency, and Blocks 2-6 are implemented. If the radar is pulse-doppler, the same calculations are performed for each PRF in Blocks 7-11. This decision is made in subroutine GETRCS after the calculation of the appropriate fluctuations table indices for the current target aspect. GETRCS then calls THRESH to calculate both fluctuations loss and integration gain. For pulse-doppler radar, THRESH is called once for each PRF, with NPULSS (i) passed to NPULSE in THRESH for the ith PRF. In RDRINT, NPULSS(i) is set equal to the user input NPULSE for all i.

Blocks 2 and 7: Before any other calculations, equation (2.25-6) is used to determine ETA, the asymptotic efficiency of the envelope detector. Note that ETA is the FORTRAN variable in THRESH that corresponds to ζ in Section 2.25.2 and [A.1-25].

Blocks 3 and 8: See Section 2.4 for description of the Signature Fluctuations FE.

Blocks 4 and 9: The nonfluctuating target detectability factor ($\overline{D}_o$) is calculated for both one pulse (ABSD1) and NPULSE pulses (ABSDN) using equation (2.25-2). These absolute values are then converted to dB (DBSNR1 and DBSNR2).

Blocks 5 and 10: Equations (2.25-8) and (2.25-1) are used to calculate integration gain (DBGAIN) from the detectability and fluctuations loss values.

Blocks 6 and 11: DBGAIN is passed as an argument back to GETRCS where it is converted to absolute units (GANINT for a pulsed radar, GNINTS (IPRF) for a pulse-doppler radar).

Integration gain is stored in a common block (RADPAR for pulsed radars, OPTPRF for pulse-doppler radars) and used in subroutine PULSED (for pulsed radars) or PULDOP (for pulse doppler radars). In these routines, integration gain is applied to the target body signal, deception jamming signal, and clutter signal.

Signal Integration Inputs and Outputs

The outputs of this functional element are the integration gains given in table 2.25-2. Only one of the two variables is produced; GANINT for pulsed radars, and the array GNINTS for pulse-doppler radars.

Table 2.25-2 Signal Integration Outputs

VARIABLE NAME	DESCRIPTION
GANINT	Integration gain for pulsed (MTI) radars
GNINTS	Array of integration gains for pulse-doppler radars, one for each PRF

These integration gains are implicitly applied to correlated signals; i.e., signals from the target body (not rotor), clutter, and deceptive jamming. This is done in subroutine PULSED for pulsed radars and in subroutine PULDOP for pulse-doppler radars.

The inputs to the Signal Integration FE are described in three types of tables: user inputs, local variable inputs, and subroutine inputs. Table 2.25-3 lists the user inputs which affect this FE. Table 2.25-4 describes local variables used in this FE that are not calculated as part of the FE; i.e., variables calculated in a different portion of a subroutine that also implements this FE. The remaining tables give descriptions of all input and output variables for subroutines. The inputs and outputs related to signal integration are printed in bold in tables 2.25-5 through 2.25-7.

Table 2.25-3 User Inputs for Signal Integration

DATABLOCK NAME	VARIABLE	DESCRIPTION
DATARADR	IRADAR	Radar Type: 1 = Pulsed (MTI) radar 2 = Pulse doppler radar
DATARADR	ISQLAW	0 = Linear detector 1 = Square-law detector
DATARADR	NPULSE	Number of pulses integrated
DATARADR	PSUBFA	Probability of false alarm
DATARADR	PSUBD	Probability of detection

Table 2.25-4 Local Variable Inputs for Signal Integration

VARIABLE NAME	SUBROUTINE	DESCRIPTION
DBLF1	THRESH	Fluctuation loss for 1 pulse (dB)
DBLFN	THRESH	Fluctuation loss for NPULSE pulses (dB)

Table 2.25-5 Subroutine GETRCS Inputs and Outputs

SUBROUTINE: GETRCS					
INPUTS			**OUTPUTS**		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
IRADAR	Common RADPAR	Radar type, 1 if pulse doppler 2 if pulse	**GANINT**	Common RADPAR	Integration gain for a pulse radar (absolute)
ISQLAW	Common RADPAR	0 = linear detection 1 = square law detector angle	**GNINTS**	Common OPTPRF	Array of integration gains for PRFs of a pulse doppler radar (absolute)
NPRFS	Common RADPAR	Number of PRFs used in a pulse doppler radar	SIGMAT	Argument	Target RCS at viewing angles AZASP and ELASP (square meters)
AZASP	Argument	Target azimuth			
CHINDF	Common RCSTAB	Array of number of degrees of freedom for chi-square and Weinstock distributions			
CORELB	Common RCSTAB	Array of number of blocks correlated for chi-square distributions			
DELAZR	Common RCSTAB	Azimuth spacing of RCS table (radians)			
DELELR	Common RCSTAB	Elevation spacing of RCS table (radians)			
ELASP	Argument	Target elevation viewing angle			
ITTYPE	Common RCSTAB	Array of fluctuation distribution types for aspect sectors			
NAZFLC	Common RCSTAB	Number of azimuth sectors in the fluctuation type table			
NAZRCS	Common RCSTAB	Number of azimuth RCS points in the table			
NELFLC	Common RCSTAB	Number of elevation sectors in the fluctuation type table			
NELRCS	Common RCSTAB	Number of elevation RCS points in the table			
NPULSE	Common RADPAR	Number of pulses integrated for pulse radar			
NPULSS	Common RADPAR	Array of number of pulses integrated for each PRF			
PI HALFPI	Common CONSTR	π $\pi/2$			
PSUBD	Common RADPAR	Probability of detection			
PSUBFA	Common RADPAR	Probability of false alarm			

Table 2.25-5 Subroutine GETRCS Inputs and Outputs

SUBROUTINE: GETRCS					
INPUTS			OUTPUTS		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
RCSSQM	Common RCSTAB	Array of RCS values for each azimuth and elevation in the RCS table (square meters)			
SIGDB	Common RCSTAB	Array of sigma parameters for log-normal distributions			
TGFLAZ	Common RCSTAB	Array of azimuth sector limits in the fluctuation type table (radians)			
TGFLEL	Common RCSTAB	Array of elevation sector limits in the fluctuation type table			

Table 2.25-6 Subroutine RDRINT Inputs and Outputs

SUBROUTINE: RDRINT					
INPUTS			OUTPUTS		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
ASIDDB	Common RADPAR	Mainlobe-to-peak sidelobe difference of the Chebychev filters (dB)	AVGMTI	Common RADPAR	Average power gain of the MTI system
AZMAXD	Common RADPAR	Maximum azimuth pointing angle of the radar antenna (degrees)	AZMAXR	Common RADPAR	Maximum azimuth pointing angle of the radar antenna (radians)
AZMIND	Common RADPAR	Minimum azimuth pointing angle of the radar antenna (degrees)	AZMINR	Common RADPAR	Minimum azimuth pointing angle of the radar antenna (radians)
AZOCLD	Common RADPAR	Maximum off-boresight angle in azimuth for which clutter returns will be computed (deg)	CONST1	Common RADPAR	Constant used in MTI calculations
BWMHZ	Common RADPAR	Radar receiver intermediate frequency bandwidth for a pulsed radar (MHz)	CONST2	Common RADPAR	Constant used in MTI calculations
CHINDR	Common RDRPD	Number of degrees of freedom for a chi-square or Weinstock target model. Used for setting the detection threshold of the radar receiver.	CONST3	Common RADPAR	Constant used in multipath calculations
CORELR	Common RDRPD	Number of correlated blocks for a chi-square target model. Used for setting the detection threshold of the radar receiver.	CONST4	Common RADPAR	Constant used in multipath calculations

Table 2.25-6 Subroutine RDRINT Inputs and Outputs

SUBROUTINE: RDRINT					
INPUTS			OUTPUTS		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
DAZCLD	Common RADPAR	Azimuth angle increment used in computing clutter returns (degrees)	CONTOR	Common RADPAR	Detection threshold (dB)
DEGRAD	Common CONSTR	Conversion factor, degrees to radians	CTAUO2	Common RADPAR	One-half the speed of light times the compressed pulse width
ELMAXD	Common RADPAR	Maximum elevation pointing angle of the radar antenna (degrees)	CTAUO4	Common RADPAR	One-fourth the speed of light times the compressed pulse width
ELMIND	Common RADPAR	Minimum elevation pointing angle of the radar antenna (degrees)	DAZCLR	Common RADPAR	Azimuth angle increment used in computing clutter returns (radians)
FILTBW	Common RADPAR	Radar filter bandwidth (Hz)	ELMAXR	Common RADPAR	Maximum elevation pointing angle of the radar antenna (radians)
FMTIDB	Common RADPAR	Minimum power response of the MTI, floor value of the MTI response (dB)	ELMINR	Common RADPAR	Minimum elevation pointing angle of the radar antenna (radians)
FPICUB	Common CONSTR	$(4\pi)^3$	ESQUAR	Common RADPAR	Constant used in Chebychev filter
FREQIN	Common RADPAR	Frequency of the radar (MHz)	FCFREQ	Common RADPAR	Center frequency of Chebychev filter. Initialized to 0.0 Hz.
IFLMOD	Common RDRPD	Target fluctuation model used to determine the detection threshold of the radar receiver	FILTBW	Common RADPAR	Radar filter bandwidth (Hz)
IRADAR	Common RADPAR	Radar type 1 = pulsed (MTI) 2 = pulse doppler	FRQFAC	Common RADPAR	Frequency factor used in calculating atmospheric attenuation
ISQLAW	Common RADPAR	Radar detector type 0 = square law 1 = linear envelope	GANOIS	Common RADPAR	Noise bandwidth of the doppler filter
NDELAY	Common RADPAR	Number of delays in the MTI	GMNMTI	Common RADPAR	Minimum power response of the MTI system
NFILTR	Common RADPAR	Number of doppler filters in the bank	IFREQ	Common RADPAR	Frequency factor used in calculating atmospheric attenuation
NPRFS	Common RADPAR	Number of pulse repetition frequencies	NAZCLT	Common RADPAR	Number of azimuths used in clutter calculations
NPULSE	Common RADPAR	Number of pulses integrated	**NPULSS**	Common OPTPRF	Number of pulses integrated for each PRF
ONETHR	Common CONSTR	1/3	PIOPRF	Common RADPAR	Array: π/f_i for each PRF f_i
PCR	Common RADPAR	Pulse compression ratio	RAMBGS	Common OPTPRF	Ambiguous range of radar (m)
PI	Common CONSTR	π	RLAMDA	Common RADPAR	Radar wavelength (m)

Table 2.25-6 Subroutine RDRINT Inputs and Outputs

SUBROUTINE: RDRINT					
INPUTS			**OUTPUTS**		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
PRFHZ	Common RADPAR	Radar pulse repetition frequency (Hz)	RUNAMB	Common RADPAR	Unambiguous range of radar (m)
PSUBD	Common RADPAR	Probability of detection	SIGMA3	Common RADPAR	$3\sigma_c$ where σ_c is RMS clutter frequency spread
PSUBFA	Common RADPAR	Probability of false alarm	STPFRQ	Common RADPAR	Constant used in Chebychev filter calculations
PSUBT	Common RADPAR	Peak power of the radar (kW)	STPFRS	Common OPTPRF	Constant used in Chebychev filter calculations
PULWID	Common RADPAR	Radar pulse width (μsec)	TARCON	Common RADPAR	Constant used in the radar range equation. Includes power, gain, loss, wave length, π, and PCR factors.
RGANDB	Common RGAINS	Boresight receive gain (dB)	TIMINT	Common RADPAR	Radar integration time (sec)
SIGDBR	Common RDRPD	Sigma parameter of a log-normal distribution			
SIGMAC	Common RADPAR	Standard deviation of the Gaussian portion of the clutter power spectral density			
SLOSDB	Common RADPAR	System losses (dB)			
TGANDB	Common TGAINS	Boresight transmit gain (dB)			
THOLDB	Common RDRPD	User-defined detection threshold (dB) for the radar receiver			
TLOSDB	Common RADPAR	Radar transmission loss (dB)			
VLIGHT	Common CONSTR	Velocity of light (m/sec)			

Table 2.25-7 Subroutine THRESH Inputs and Outputs

SUBROUTINTE: THRESH					
INPUTS			**OUTPUTS**		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
ISQLAW	Argument	0 =Linear detector 1 =Square-law detector	CONTOR	Argument	The one-pulse signal-to-noise ratio (dB) required for target detection
NPULSE	Argument	Number of pulses integrated	**DBGAIN**	Argument	The integration gain (dB) for NPULSE pulses integrated
PSUBFA	Argument	Probability of false alarm			
PSUBD	Argument	Probability of detection			

Table 2.25-7 Subroutine THRESH Inputs and Outputs

<table>
<tr><th colspan="6">SUBROUTINTE: THRESH</th></tr>
<tr><th colspan="3">INPUTS</th><th colspan="3">OUTPUTS</th></tr>
<tr><th>NAME</th><th>TYPE</th><th>DESCRIPTION</th><th>NAME</th><th>TYPE</th><th>DESCRIPTION</th></tr>
<tr><td>ITYPE</td><td>Argument</td><td>Fluctuation type indicator
0 =Non-fluctuating
1 =Swerling 1
2 =Swerling 2
3 =Swerling 3
4 =Swerling 4
5 =Chi-square
6 =Weinstock
7 =Log-normal</td><td colspan="3" rowspan="4"></td></tr>
<tr><td>CHNDF</td><td>Argument</td><td>Number of degrees of freedom for chi-square or Weinstock distribution</td></tr>
<tr><td>CORLB</td><td>Argument</td><td>Number of blocks correlated for chi-square distribution</td></tr>
<tr><td>SIGDB</td><td>Argument</td><td>Sigma parameter of log-normal distribution</td></tr>
</table>

2.25.4 Assumptions and Limitations

The radar detection-envelope type must be either linear or square-law.

The probabilities of detection and false alarm must lie within the following bounds:

$$0.1 \leq P_d \leq 0.9 \text{ and } 10^{-12} \leq P_{fa} \leq 10^{-4}$$

The equivalent number of pulses integrated is assumed to be equal to the (user input) number of pulses integrated. This is a valid assumption for cases with an ideal or uniform-weight integrator and no signal variation. For other types of integrators, or cases with signal variation (due to the movement of the radar beam across the target), the user must precalculate the equivalent number of pulses integrated and input that value as NPULSE.